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In accordance with the proposal, the DURIP funds were devoted primarily to (1) the improvement of the existing optical instrucmentation; and (2) the purchase of a variable temperature acanning tunneling microscope head and related assemblies. These purchased, supplementing our existing optical and surface science capabilities, have permitted us to develop state-of-the-art facilites for the study of surfaces with spatial resoluation on the atomic scale and temporal resolution on the femtosecond time scale.

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Final Technical Report for DURIP-96 Grant for an Apparatus with Femtosecond Time Resolution and Atomic Spatial Resolution for the Study of Surface Processes Induced by High Intensity Ultrafast Laser Pulses

Grant Number: F49620-96-1- 0406

Period: August 1, 1996 – January 31, 1998

Principal Investigator: Prof. Tony F. Heinz

Overview

This report summarizes the equipment purchased and the new capabilities developed under the Defense University Research Instrumentation Program DURIP grant F49620-96-1- 0406 entitled "Apparatus with Femtosecond Time Resolution and Atomic Spatial Resolution for the Study of Surface Processes Induced by High Intensity Ultrafast Laser Pulses."

The attached listing indicates the disposition of the funds provided under the DURIP grant. Cost sharing towards this grant using Columbia University funds contributed to the development of the needed experimental capabilities. These funds were used both to purchase related items and for direct cost sharing of items on the attached list.

In accordance with the proposal, the DURIP funds were devoted primarily to (1) the improvement of the existing optical instrumentation; and (2) the purchase of a variable temperature scanning tunneling microscope head and related assemblies. These purchases, supplementing our existing optical and surface science capabilities, have permitted us to develop state-of-the-art facilities for the study of surfaces with spatial resolution on the atomic scale and temporal resolution on the femtosecond time scale.

The improvements in the ultrafast laser and optical capabilities directly support our investigations under an AFOSR grant (No. F49620-98-1-0137) entitled "Optoelectronic Generation and Control of Intense GHz/THz Radiation", and under a JSEP grant (No. DAAG55-97-1-0166) entitled "Extending the Useful Range of the Electromagnetic Spectrum." The development of new surface science capabilities benefits these research programs through our dramatically upgraded materials characterization infrastructure. These capabilities also directly enhance our abilities to conduct research supported through a grant from the NSF (No. CHE-96-12294) entitled "Probing Far-Infrared Excitations of Surfaces and Thin Films by Optoelectronic Techniques." In addition, the new capabilities are of importance for research under a major multi-investigator grant currently in final review by the DOE and the NSF. Further research initiatives that will make direct use of our new experimental capabilities are now being developed as new proposals for government funding.

Major New Experimental Facilities Provided by DURIP Funding

The single most significant enhancement of our experimental capabilities was provided by the purchase of a variable-temperature scanning tunneling microscope (STM) head and associated assemblies. This complements our existing ultrahigh vacuum (UHV) system equipped with various surface analytic and preparation tools including Auger electron spectroscopy (AES), low-energy electron diffraction system (LEED), quadrupole mass spectroscopy (QMS), and ion sputtering. The variable temperature STM was purchased from Omicron Associates (Model VT-STM).

This STM system is designed for cooling and heating the sample between 25 K and, depending on the sample material, up to 750 K/1400 K using indirect/direct current heating. The vibration isolation of the STM head allows real space imaging of surfaces with atomic resolution. The sample is cooled by a flexible connection to a constant flow liquid helium cryostat. This cooling connection can be opened and closed using a screw driver wobble stick port without opening the chamber in order to enable sample transfer. A temperature regulator controls the counter-heating of the sample allowing a continuous adjustment of the sample temperature and stable operation at any temperature. Both samples and tips can be stored in a storage carousel and transferred to the other analytic and preparation devices within the vacuum chamber using a wobble stick.

The STM uses a single tube scanner with a scan range of 10×10 μm and a z-travel of 2 μm. A z-resolution of less than 10 pm can be achieved. Typical scan speeds are 100-1000 nm/s. The 3-dimensional coarse positioning system allows access to any part of the sample surface, which has typical dimensions of 2×9 mm. The coarse approach of the tunneling tip to the surface is done manually using a CCD camera, whereas the final approach to within a 1 nm is done automatically by the control software. The measurement control software, which was purchased through other funding sources, is used to change the scan parameters (tunneling voltage, current, frame size, scan speed) and display the image of the surface in real time. Standard filtering and image enhancement procedures can be applied for quick evaluation of the data. The software further allows the acquisition of spectroscopic data in combination with regular imaging.

Several smaller equipment purchases were made to complete installation of the STM in our existing UHV chamber and to upgrade some critical parts of our pumping system. In addition, an improved data acquisition system was purchased to interface the controller. (Please see attached listing.)

Substantial improvements were also made in optical and ultrafast laser capabilities under the DURIP grant. These included an upgrade for our existing Bomem DA-3 Fourier-transform infrared spectrometer to enhance the responsivity in the far-infrared spectral region and the purchase of a deuterium light source to produce a beam with high intensity in the ultraviolet spectral region. The latter unit can be directly attached to one of the ports of the UHV system and provide radiation to the sample when installed in the STM. DURIP funds were used to purchase new devices for laser-based far-infrared generation and detection. DURIP funds were also devoted to the purchase of optical components to improve the performance and characterization of an existing

chirped-pulse regenerative amplifier for modelocked Ti:sapphire laser pulses. This amplified ultrafast system, which is seeded by an existing commercial Ti:sapphire oscillator, can provide sub-100 femtosecond laser pulses of gigawatt power at a wavelength of 800 nm. This system can be readily configured to provide optical excitation for the surface science apparatus described above.

Apple Computer	Powermac 8600 for data acquisition	$3,375.00
Atomergic Chemetals Corp.	Semiconductor emitters	$301.12
Atramet, Inc.	Undoped semiconductor wafers	$318.84
Bomen, Inc.	Far-IR electronics for FT spectrometer	$6,179.00
Club Mac	Memory module	$183.90
Columbia Hardware	Electrical cables	$80.21
CVI Laser Corp.	Ultrafast dielectric mirrors	$1,357.74
DS&D	Storage assembly	$1,086.59
Excel Quantronix	LBO Crystal for pump laser of regen amplifier	$2,416.00
Goodfellow	Tungsten filament	$79.00
Hamamatsu	Avalanche photodiodes	$679.88
Implant Sciences	Far-infrared detector	$1,387.38
Institut fuer Allgemeine Physik	Data acquisition system	$1,533.50
Kurt J. Lesker	UHV fittings, gaskets, sealant	$1,561.59
Lab Line Instruments	Gasket for Liquid Nitrogen Dewar	$38.55
New Focus, Inc.	Laser mirrors	$573.00
New Focus, Inc.	Photoreceiver	$1,205.85
Newark Electronics	Electronic components	$695.81
Newark Electronics	Cables and Connectors	$179.75
Newport Corp.	Ultrafast beamsplitter, lenses	$1,856.95
Newport Electronics	Optical mounting plates	$511.25
Omicron Associates	Scanning Tunneling Microscope	$24,676.20
Omicron Associates	Scanning Tunneling Microscope	$72,144.04
Oriel Instruments	High-intensity optical source	$4,039.39
Pfeiffer Vacuum	Turbo Pump component	$88.39
Physical Electronics	Bakeout heater apparatus	$575.10
R.S. Crum	Vacuum fittings	$105.37
Total		$127,229.40